Technical Report 596

VARIABILITY OF PRACTICE AND THE TRANSFER OF TRAINING OF MOTOR SKILLS

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BASIC RESEARCH

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Two hundred and eighty-eight righthanded males were trained in either an open skill or closed skill situation in order to determine whether the amount and variability of practice enhanced transfer to nonpracticed tasks of a similar nature. Subjects in the open skill situation visually tracked a moving light sequence and attempted to complete a ballistic arm movement coincident with the termination of light movement. Closed skill subjects did not receive the light sequence but focussed their attention on the production of a specific

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movement time on each trial. Subjects in both situations received either 45 or 180 trials during the training phase. Open skill subjects practiced with a stimulus velocity-movement distance combination which remained constant or was varied during training. Closed skill subjects practiced movement time-movement distance combinations which remained the same or were varied from trial to trial during training. Following the training phase open skill subjects performed 20 trials with a stimulus velocity-movement distance they had not experienced before while closed skill subjects attempted to produce a new movement time-movement distance combination.

During the training phase open skill subjects who practiced with a variety of movement distances exhibited higher absolute timing error than those who practiced with a constant distance. This effect dissipated quickly however and transfer performance did not appear to be influenced differentially by constant or varied training conditions. For closed skill subjects, variations in movement time, and to a lesser extent movement distance resulted in higher absolute error during training. Moreover, the transfer performance of subjects who trained with a variety of movement times and/or movement distances was less accurate and less consistent than that of subjects receiving training with a constant movement time and/or distance. It was suggested that if closed skill transfer will ultimately be to a single novel version of a particular task (e.g., repeatedly throwing a grenade at a new target) training should primarily involve the constant repetition of a single response (particularly with respect to a constant movement time). On the other hand open skill transfer should not be influenced as much by different levels of variability during training.

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FOREWORD

The Training and Simulation Technical Area of the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) maintains a program of research in support of the systems approach to training. A major focus of this program is the development of fundamental data and technology in the areas of skill acquisition, retention and transfer necessary for fielding training systems that improve individual job performance.

Typically, soldiers are trained in service schools on only a portion of those tasks required for effective job performance. The remaining tasks are trained on the job once soldiers arrive in their operational units. Because unit training resources are limited, a primary goal of school training is to promote effective positive transfer of school-taught tasks to those additional tasks required on the job. Such transfer would reduce unit training demands and promote better on-the-job performance and associated combat readiness.

This basic research report examines the effects of amount and variability of practice on the transfer of training of motor skills. The findings indicate that transfer improves with increased initial task training but that the effects of variety are task specific. These and other previous findings from the Training and Simulation Technical Area are being combined to form the technology base for improving training and training management effectiveness within the Army.

Edgar M. Johnson
Technical Director

VARIABILITY OF PRACTICE AND THE TRANSFER OF TRAINING OF MOTOR SKILLS

BRIEF

Requirement:

To determine whether the amount and variability of movement practice during motor skills training enhances transfer of training to nonpracticed tasks of a similar nature; to examine the effects of amount and variability of practice for both "open" and "closed" motor skills (open skills require responses to changing environmental conditions while closed skills are performed in a relatively stable environment); to suggest potential application of the findings in the training of military personnel in order to promote more effective transfer of motor skills essential for combat readiness.

Procedure:

Two hundred and eighty-eight righthanded males were trained in either an open skill or closed skill situation. Both situations involved a ballistic horizontal arm sweep from a start button to a hinged target. Subjects in the open skill condition visually tracked a moving light sequence and attempted to complete their response coincident with the termination of light movement. Closed skill subjects did not receive the light sequence but attempted to produce a specified movement time on each trial. During training subjects were given either 45 or 180 trials of practice. Variability of practice was manipulated in the closed skill condition by requiring subjects to perform a movement distance-movement time combination which either varied or remained constant from trial to trial. In the open skill situation movement distance and stimulus velocity were varied or remained constant during training. Knowledge of results in terms of timing error (in milliseconds) were administered after each trial. Following training closed skill subjects attempted to produce a movement distance-movement time combination which they had not previously performed. Similarly open skill subjects were given a new stimulus velocity and movement distance. No knowledge of results were given during the transfer phase.

Findings:

For the closed skill situation, variations during training in movement time and, to a lesser extent, movement distance resulted in higher absolute timing error during the training phase and higher absolute error and variable error in the production of a novel movement distance-movement time combination during the transfer phase. In the open skill situation, variations in movement distance elicited initial elevations in absolute timing error during training but this effect dissipated after about 30 trials. Moreover, manipulations of the variability of movement distance and stimulus velocity during the training phase appeared to exert little influence on coincident timing in a novel stimulus velocity-movement distance situation. Subjects who were trained under fixed movement distance or stimulus velocity conditions significantly reduced their variable error over transfer blocks while variable trained subjects did not. Subjects who received 180 trials during the training phase generally performed better during the transfer phase than subjects who received 45 training trials.

Utilization of Findings:

Decisions regarding the quality and quantity of training experiences would appear to be more crucial for the learning of closed motor skills (e.g., throwing a hand grenade at a fixed target) than open skills (e.g., accurate estimation of the moment of initiation of an anti-tank response). If transfer is to a single novel version of a particular closed skill (e.g., repeatedly throwing a grenade at a new target) it appears that the trainee would benefit more from constant repetition of a single response (particularly with respect to a constant movement time) during training.

VARIABILITY OF PRACTICE AND THE TRANSFER OF TRAINING OF MOTOR SKILLS

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Variability of Practice and the Transfer of Training of Motor Skills

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Two fundamental issues in the learning of motor skills deal with the quality and quantity of practice sessions. In order to maximize the efficiency and minimize the cost of training, decisions must be made regarding the optimal amount and type of practice which will best facilitate learning. One approach to this issue has recently been proposed by Schmidt (1975) who has suggested that the skill acquisition process be viewed as an attempt by the performer to develop general rules of movement which are then used to govern the production of future responses. At the heart of this veiwpoint is the notion that a variety of perceptual-motor experiences during training will promote rule formation to a greater extent than repetition of a single movement. If Schmidt's proposition is correct then the practical implications are clear: traditional training strategies which emphasize the mere repetition of responses may need to be amended to include greater variation of perceptual and/or motor experiences.

Schmidt's (1975) schema theory is rooted in the notion of generalized motor programs. For example, the motor action involved in throwing might be postulated to require a generalized program which could be activated to throw an object faster or slower, higher or lower, and overhand or sidearm. In addition, objects of different shapes, sizes, and weights might also be accommodated by this program. The idea of the generalized program has a good deal more theoretical and practical appeal than the notion that a variety of related movements (e.g., throwing a hand grenade and throwing a knife) require separate motor programs for execution (Henry & Rogers, 1960).

According to Schmidt (1975) the four sources of information which subjects use to construct the generalized program are those concerning a) the preresponse state of the muscular system and the environment (i.e., initial conditions), b) the motor plan for generating the movement (i.e., response specifications), c) feedback stimuli resulting from the actual movement (i.e., sensory consequences), and d) the success of the response in achieving the originally-intended outcome (i.e., degree of goal achievement). The chief aim of practice on a given task is to provide the performer an opportunity to repeatedly generate and/or experience the above four sources of information. After a number of trials, the subject presumably begins to abstract a <u>relationship</u> between the various types of information. This abstracted relationship becomes what Schmidt (1975) terms the generalized program or "schema" for the particular movement class (e.g., throwing). According to Schmidt, a generalized throwing program should allow the performer to adapt to each throwing situation by manipulating the parameters of the program (e.g., amount of force, direction of throw, selection of appropriate muscle groups) to suit the particular circumstances.

An important prediction of Schmidt's theory is that schema strength is a function of the amount and variability of perceptual-motor training experiences. To test this notion studies have typically employed an experimental paradigm involving a variable practice group which is given several versions of the task during training and a constant practice group which receives only one version. At the end of training, the groups are transferred to an instance of tha task which has not been previously experienced by either group. Such a paradigm is not new, having been used for some time by experimental psychologists to study the development of cognitive-conceptual relationships using tasks such as paired associate learning (Duncan, 1958), geometrical figure discrimination (Morrisett & Hovland, 1959), and serial learning of noun lists (Baker, Santa, & Gentry, 1977) and of letters (Ellis, Parente, Grah, & Spiering, 1975).

Direct tests of Schmidt's (1975) schema theory for discrete motor skills using the transfer paradigm have produced mixed results. While there has been consistent support for the variability of practice hypothesis from experiments with children (Beatty, 1977; Carson & Wiegand, 1979; Kelso & Noman, 1978; Kerr & Booth, 1977, 1978; Moxley, 1979; Pigott, 1979) the results from studies with adult subjects have been more equivocal. The majority of the latter investigations have employed rapid (i.e., movement times less than 1 sec) timing tasks involving short (i.e., movement distances less than 75 cm) subject-paced arm movements with variations in either movement time or movement distance.

In the only study using a fixed movement distance, Newell and Shapiro (1976) trained subjects to make a 10.16 cm movement in a time of either 70 msec or 130 msec. Constant practice subjects performed 60 trials with knowledge of results at either the 70 or the 130 msec movement time while varied practice subjects received the first half of their trials with either the 70 msec or 130 msec movement time and the second half at the other time (the order of presentation of movement times was counterbalanced). Half of the subjects in each condition then attempted to perform 20 trials of the task at a movement time of 100 msec while the other half attempted to produce a movement time of 180 msec. No knowledge of results were given during the transfer trials. Mixed support was generated for the schema notion when the varied practice subjects who received training trials with the 70 msec movement time followed by the 130 msec movement time transferred to the 180 msec movement time with significantly less error than constant practice subjects. Therefore it was suggested that the order of variable practice might facilitate transfer to a second task when the movement time for that task was outside the range of movement times given during training.

In studies utilizing a fixed movement time and varied movement distance there has again been partial support for the schema notion. McCracken and Stelmach (1977) trained subjects to produce a movement ranging in length from 15-65 cm in a time of 200 msec. During training variable practice subjects received an equal number of trials (K = 75) with each distance while constant practice subjects received 300 trials on only one of the movement distances. Control subjects received 75 trials of practice with one of the distances. In both the constant practice and the control conditions an equal number of subjects were assigned to each movement distance. When transferred to a 50 cm distance for 30 trials without knowledge of results, the variable practice condition exhibited significantly lower absolute error than the other groups. In a similar experiment conducted by Zelaznik (1977) variable practice subjects attempted to move distances of 15, 25, and 33 cm (24 trials/distance) in a time of 200 msec while constant practice subjects received either 24 or 72 trials with the 33 cm distance. Accuracy of transfer performance at a distance of 43 cm was not found to be significantly different for the three groups. An important methodological difference characterizing the Zelaznik (1977) study was that all constant practice subjects were trained at the distance closest in length to the transfer distance. Thus, had variable practice subjects demonstrated superior transfer more powerful support for the schema notion would have been generated.

Taken together, the results of these studies performed in a relatively stable environment and referred to as "closed skills" (Poulton, 1957) provide only modest support for the variability of practice hypothesis. In the only published experiment investigating timing performance in an "open skill" setting (i.e., with environmental uncertainty added) initial support for the schema notion was produced. Wrisberg and Ragsdale (1979) presented subjects with a moving visual stimulus (i.e., lights illuminating in a pattern of apparent motion) and instructed them to press a button at the same moment that they perceived the last lamp in the sequence was illuminating. Prior to transfer trials with a stimulus velocity of 402 cm/sec subjects received 40 trials in which they either a) watched, or b) responded to stimuli which a) varied in speed from trial to trial (velocities ranged from 224 cm/sec to 581 cm/sec) or b) were the same on each trial. During transfer trials the high variability group which overtly responded to the visual sequences during training had significantly lower absolute error than the other conditions. It was suggested however that further study be done using longer limb movements in order to determine the relative contributions of variations in stimulus (e.g., velocity) and response (e.g., movement distance) parameters to the development of a generalized program for open skills.

The present study represented an initial attempt to identify the relative contribution of spatial and temporal components in the development of generalized programs for open and closed timing tasks. During training the amount and variability of practice were independently manipulated. Following the training phase subjects were transferred to a novel version of their respective tasks which they performed without knowledge of results.

Method

Subjects. A total of 288 male righthanded subjects participated in the experiment. All of the participants were students at the University of Tennessee, ranging in age from 18 to 30 years. None of the subjects was familiar with the test apparatus and all were paid for their participation.

Apparatus. Five microswitches and a hinged and foam-padded plywood target (11 x 13 cm) were attached to a platform which was mounted on top of a large table. The 1.5 cm diameter microswitches were separated (center to center) by a distance of 15 cm and mounted along a line parallel to and 18 cm from the edge of the table. The distance from the target to the first microswitch was 43 cm and to the second, third, fourth, and fifth microswitches 58, 73, 88 and 103 cm, respectively. A Reaction-Movement Timer (Lafayette Instruments #62017) was interfaced with the response system. When the target was in the vertical position it depressed a set of contact points. In the closed skill situation time began to accumulate on the Reaction-Movement Timer when the subject released one of the response microswitches and stopped when the target was knocked over, opening the contacts.

A Bassin Anticipation Timer (Lafayette Instruments #50-575) was interfaced with the response platform for use in the open skill situation. This system included a solid state control unit and a runway which was 285 cm long x 9 cm high x 7 cm wide. Mounted on top and running the length of the runway were 64 small (.5 cm diameter) lamps, separated center to center by a distance of 4.45 cm. The runway was mounted in a line extending out from the target and parallel to the response microswitches. In the open skill situation target contact resulted in a digital display which indicated the algebraic difference (i.e., early vs. late target contact) in msec between the moment of target contact and the moment of illumination of the last lamp (i.e., the one nearest the target) in the sequence.

Procedure. The experiment was composed of two phases, a training phase and a transfer phase (Table 1). Subjects assigned to the closed skill situation were instructed to produce a particular movement time on each training trial. The subject stood facing the response platform with the target situated to his left. Prior to each trial the subject was told a movement time which he was to attempt to produce. He was then instructed to depress one of the response microswitches with the index finger of his right hand (Figure 1). When he was ready the subject made a ballistic right to left arm movement from the microswitch to the hinged target (Figure 2), attempting to traverse the distance in the instructed movement time. Following each trial the experimenter verbally reported the actual movement time produced (in msec) and indicated whether it was faster or slower than the instructed time. The spatial and temporal factors manipulated during training in the closed skill situation were movement distance and movement time, respectively. As indicated in Table 1, closed skill subjects received either 45 or 180 training trials in which movement distance and/or movement time was either constant or varied from trial to trial. An equal number of subjects ($n = 18$) were randomly assigned to each of the eight possible combinations of training trials (2) x movement distance (2) x movement time (2). Following training all closed skill subjects performed 20 transfer trials without knowledge of results in which they attempted to move a distance of 43 cm in a time of 300 msec.

Subjects assigned to the open skill situation were instructed to produce a ballistic movement which terminated with target contact at the same moment that the last lamp in a sequence of runway lights was illuminating. As in the

Table 1

Experimental Design

Type of Task	Training Phase: Number of Trials	Training Phase: Movement Distance	Training Phase: Movement Time*	Transfer Phase: Number of Trials	Transfer Phase: Movement Distance	Transfer Phase: Movement Time*
Closed	45 or 180	Fixed (58 cm)	Fixed (400 msec)	20	43 cm	300 msec
	45 or 180	Varied (58, 73, and 103 cm)	Fixed (400 msec)	20	43 cm	300 msec
	45 or 180	Fixed (58 cm)	Varied (400, 600, and 700 msec)	20	43 cm	300 msec
	45 or 180	Varied (58, 73, and 103 cm)	Varied (400, 600, and 700 msec)	20	43 cm	300 msec
Open	45 or 180	Fixed (58 cm)	Fixed (224 cm/sec)	20	43 cm	179 cm/sec
	45 or 180	Varied (58, 73, and 103 cm)	Fixed (224 cm/sec)	20	43 cm	179 cm/sec
	45 or 180	Fixed (58 cm)	Varied (224, 268, and 358 cm/sec)	20	43 cm	179 cm/sec
	45 or 180	Varied (58, 73, and 103 cm)	Varied (224, 268, and 358 cm/sec)	20	43 cm	179 cm/sec

* "Stimulus Velocity" for the open skill situation

Figure 1.

Subject Standing at Apparatus in
"Ready" Position (Closed Skill Situation)

Figure 2.

Subject Contacting Target at Completion of Timing Movement (Closed Skill Situation) closed skill situation the subject stood in front of the response platform with the target to his left and the runway extending horizontally out from the target. Prior to each trial the subject was instructed to depress one of the microswitches with the index finger of his right hand. He was then told to turn his head to the left and to focus his attention on the furthest end of the runway (Figure 3). This instruction was designed to orient the subject for subsequent visual tracking of the sequence of apparent motion. When this occurred the subject watched the moving stimulus and then attempted to produce a ballistic right-left arm response, originating from the micro-switch and terminating at the target at the same moment that the last lamp on the runway nearest the target was illuminating (Figure 4). Following each training trial the experimenter verbally reported the difference (in msec) between the moment of illumination of the last lamp and the moment of target contact. The subject was also told whether target contact was made "too early" (i.e., before the last lamp illuminated) or "too late" (i.e., after cessation of the illumination period for the last lamp). The spatial and temporal factors manipulated during training in the open skill situation were movement distance and stimulus velocity, respectively. As indicated in Table 1 open skill subjects received either 45 or 180 training trials in which movement distance and/or stimulus velocity was either constant or varied from trial to trial. An equal number of subjects (n = 18) were randomly assigned to each of the eight possible combinations of training trials (2) x movement distance (2) x stimulus velocity (2). Following training all open skill subjects performed 20 transfer trials without knowledge of results in which they moved a distance of 43 cm in an attempt to time the completion of a visual stimulus moving at a speed of 179 cm/sec.

Closed skill subjects in the varied-varied condition received an equal

Figure 3.

Subject Standing at Apparatus in
"Ready" Position (Open Skill Situation)

Figure 4.

Subject Contacting Target at Completion of
Coincident Timing Movement (Open Skill Situation)

number of trials with each of the nine possible combinations of movement distance and movement time. Open skill subjects assigned to the varied-varied condition performed an equal number of trials with each of the nine possible combinations of movement distance and stimulus velocity. Groups which practiced with one fixed and one varied factor received an equal number of trials with each of the three levels of the varied factor. Subjects who received 180 training trials were given a two-minute rest between each block of 45 trials and, for all subjects, a two-minute rest was interpolated between the training and transfer phases of the experiment. An intertrial interval of 10 sec was maintained throughout training and transfer performance.

Results

Measures

Training. The dependent measure of interest was mean absolute error (AE). For the closed skill situation AE represented the absolute difference (in msec) between actual and desired movement time averaged for each subject over blocks of five trials. For open skill subjects AE was calculated as the absolute difference (in msec) between the moment of target contact and the moment of illumination of the last lamp in the runway sequence. These scores were also averaged over blocks of five trials for each subject.

Transfer. Three dependent measures were recorded during the transfer phase of the experiment. In addition to AE (averaged for each block of five trials), constant error (CE) and variable error (VE) were also derived from the scores of each subject. The former measure represented the algebraic deviation of a subject's response from the correct movement time (closed skill) or moment of coincidence (open skill), averaged over each block of five trials. The VE measure was obtained by calculating the standard deviation of a subject's CE scores around his mean CE for each block (see Schutz & Roy, 1973, for a more detailed discussion of these measures).

Closed Skill Training

The mean AE scores for closed skill subjects were assessed by a movement distance (2) x movement time (2) x blocks ANOVA with repeated measures on the last factor. Separate ANOVAs were run for subjects receiving 45 training trials (9 blocks) and for those receiving 180 training trials (36 blocks). Both ANOVAs revealed a highly significant three-way interaction of movement distance x movement time x blocks, $F(8,544) = 5.94$, $p < .001$ (9 blocks), and $F(35,2380) = 3.30$, $p < .001$ (36 blocks). These interactions are presented in Figures 5 and 6. In each case it is clear that while decreases in timing error were taking place for all groups over blocks, those subjects who received a variety of movement times during training produced higher errors than those who trained with a constant movement time. Only when movement time was varied did further variations in movement distance appear to result in greater timing error; however, this effect seemed to disappear after about 24 blocks (or 120 trials) of practice (Figure 6).

Closed Skill Transfer

The mean AE, CE, and VE scores for closed skill subjects were assessed by means of separate training trials (2) x movement distance (2) x movement time (2) x blocks (4) ANOVAs with repeated measures on the last factor. A Newman-Keuls post hoc analysis was performed to locate the source of significant differences involving three or more means.

Absolute error. The only significant effects obtained for AE were the main effects of training trials, $F(1,136) = 10.27$, $p < .01$, and of movement time, $F(1,136) = 6.50$, $p < .01$. As can be seen in Figure 7 AE during the production

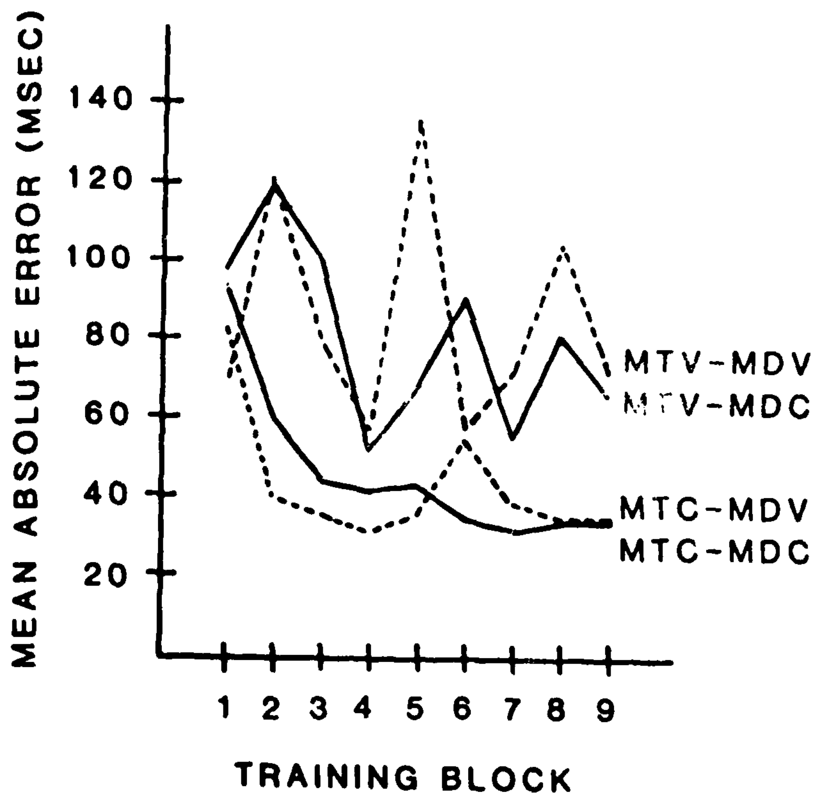

Figure 5.

Mean Absolute Error During the Training Phase for the Movement Distance x Movement Time x Blocks Interaction for Closed Skill Subjects Receiving 45 Trials (9 Blocks)

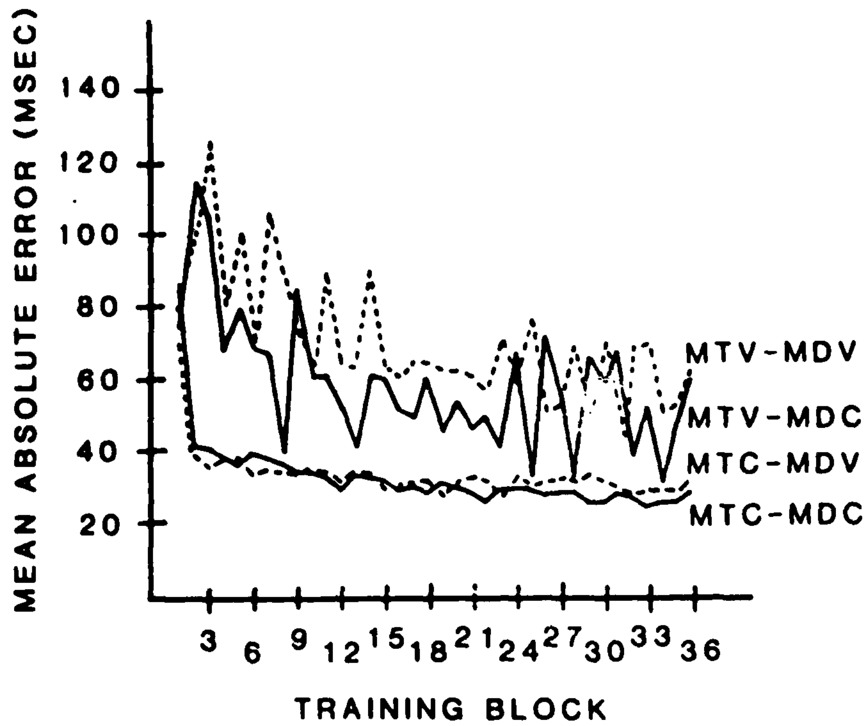

Figure 6.

Mean Absolute Error During the Training Phase for the Movement Distance x Movement Time x Blocks Interaction for Closed Skill Subjects Receiving 180 Trials (36 Blocks)

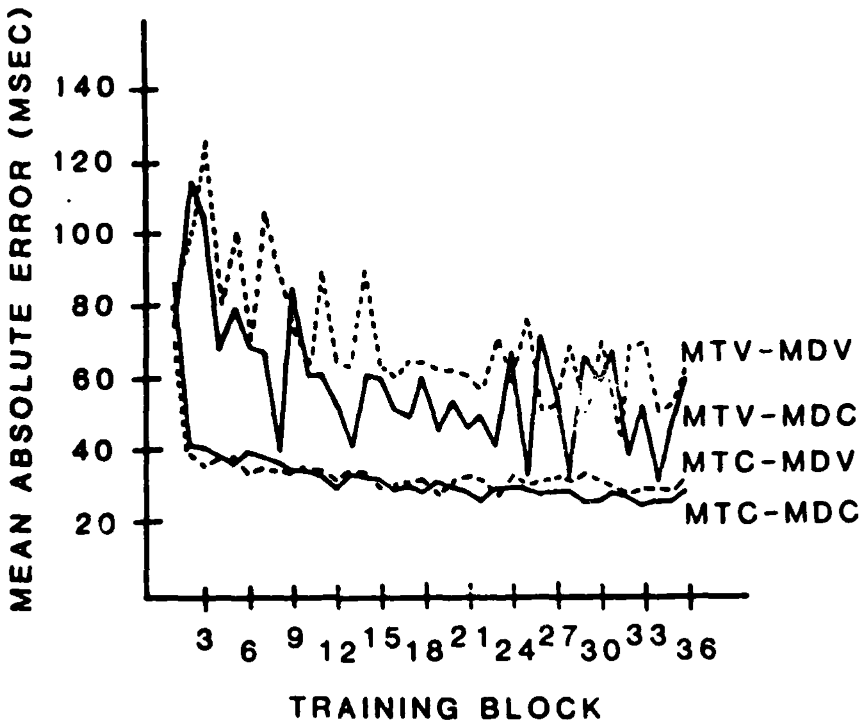

Figure 6.

Mean Absolute Error During the Training Phase for the Movement Distance x Movement Time x Blocks Interaction for Closed Skill Subjects Receiving 180 Trials (36 Blocks)

of a novel movement distance-movement time combination was lower for subjects who received a greater number of training experiences and for those who attempted to produce a constant movement time during training.

Constant error. No significant main or interaction effects were obtained for CE. Thus, it appeared that neither the amount nor the type of training produced any bias (i.e., responses that on the average were too fast or too slow) in the execution of the novel transfer movement.

Variable error. For VE, significant main effects were obtained for training trials, $F(1,136) = 4.54$, $p < .05$, movement distance, $F(1,136) = 6.66$, $p < .01$, movement time, $F(1,136) = 8.95$, $p < .01$, and blocks, $F(1,136) = 3.64$, $p < .01$. As can be seen in Figure 8, average within-subject variability in the production of the novel movement distance-movement time combination was lower for subjects who a) received more training trials, b) trained with a constant movement distance, and c) trained with a constant movement time. Figure 9 presents the means for the significant blocks effect. Inspection of this figure indicates that the largest reduction in VE occurred from the first block of transfer trials to the second block. Newman-Keuls procedures revealed that VE on Block 1 was significantly different from that on Block 2 ($p < .01$) and Block 4 ($p < .05$). Thus, it appeared that all subjects settled into a preferred movment pattern fairly early in the transfer phase and, in the absence of knowledge of results, tended to repeat that movement with the same level of consistency over the remaining transfer trials. No other significant main or interaction effects were obtained for VE.

Open Skill Training

The mean AE scores for open skill subjects were assessed by a movement distance (2) x stimulus velocity (2) x blocks ANOVA with repeated measures on the last factor. Separate ANOVAs were performed on the data of subjects re-

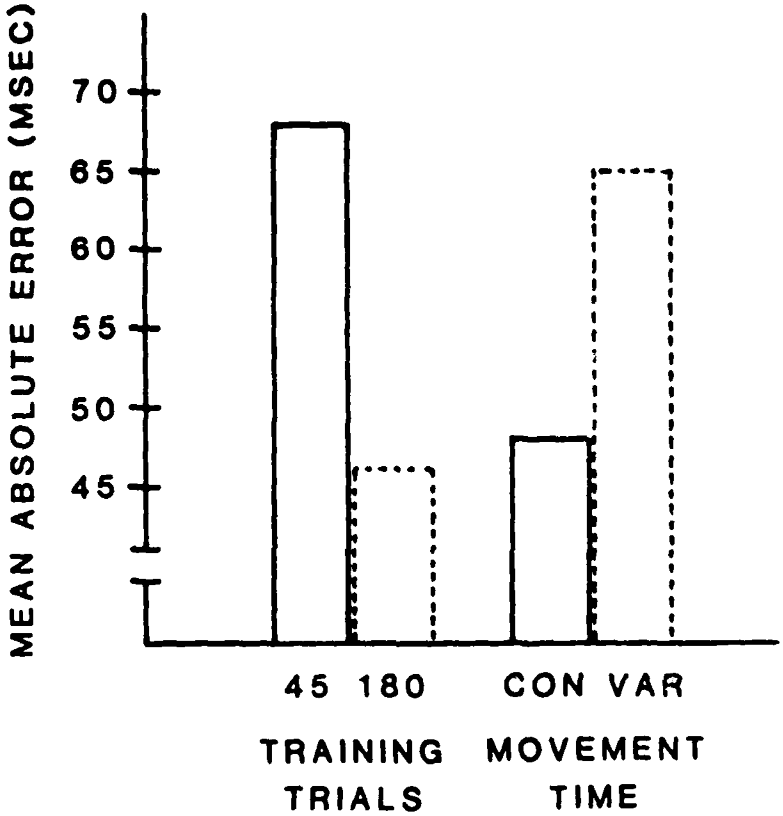

Figure 7.

Mean Absolute Error for the Closed Skill Transfer Phase as a Function of Number of Training Trials and Movement Time Condition During Training

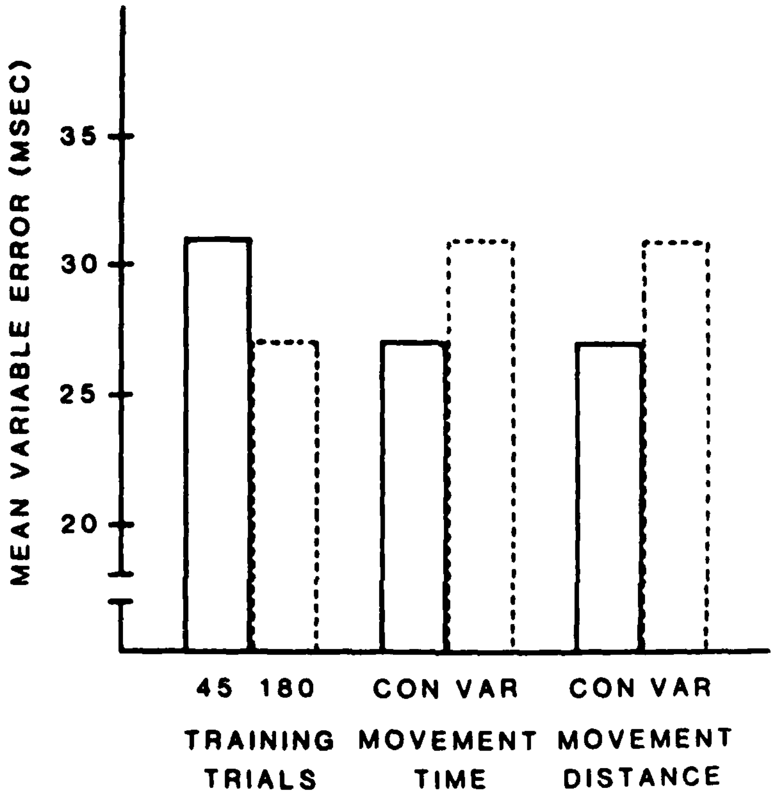

Figure 8.

Mean Variable Error for the Closed Skill Transfer Phase as a Function of Number of Training Trials, Movement Time Condition During Training, and Movement Distance Condition During Training

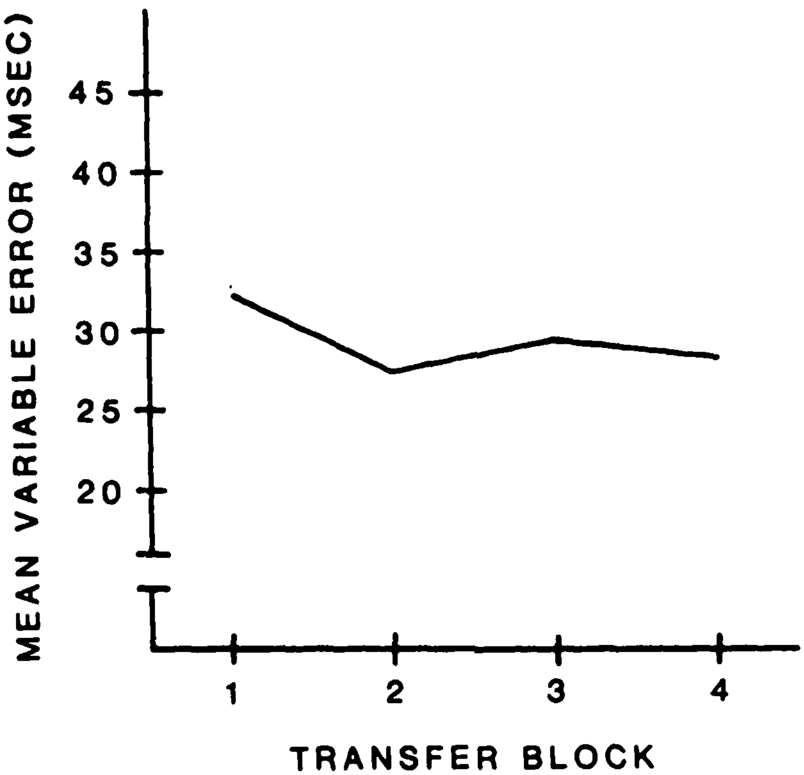

Figure 9.

Mean Variable Error for the Four Blocks of Trials During the Closed Skill Transfer Phase ceiving 45 training trials (9 blocks) and those of subjects receiving 180 training trials (36 blocks). For the former analysis, significant main effects were found for movement distance, $F(1,68) = 3.85$, $p < .05$, and for blocks, $F(8,544) = 7.98$, $p < .01$. In Figure 10 the means are presented for the groups receiving fixed and varied movement distances during 9 blocks of training trials. It appeared that while both groups improved the absolute accuracy of their coincidence responses over blocks, subjects who trained at various movement distances, experienced greater difficulty in timing the completion of the moving light stimulus. The ANOVA conducted on the scores of subjects receiving 180 trials during the training phase seemed to indicate that the impact of variations in movement distance was becomming less noticeable with extended practice. Figure 11 graphically illustrates that by about Block 7, AE scores for fixed and for varied movement distance groups were not appreciably different. In addition to a significant main effect of blocks, $F(35,2380) = 12.63$, $p < .001$, there was a significant interaction of movement distance and blocks, $F(35,2380) = 1.72$, $p < .01$, which supported the notion that the influence of variations in movement distance was present only during early training trials. No other significant main or interaction effects were found for AE during the training phase of the study.

Open Skill Transfer

The mean AE, CE, and VE scores for open skill subjects were assessed by means of separate training trials (2) x movement distance (2) x stimulus velocity (2) x blocks (4) ANOVAs with repeated measures on the last factor. A Newman-Keuls post hoc analysis was performed to locate the source of significant differences involving three or more means.

Absolute error. The analysis of AE revealed no significant main or inter-

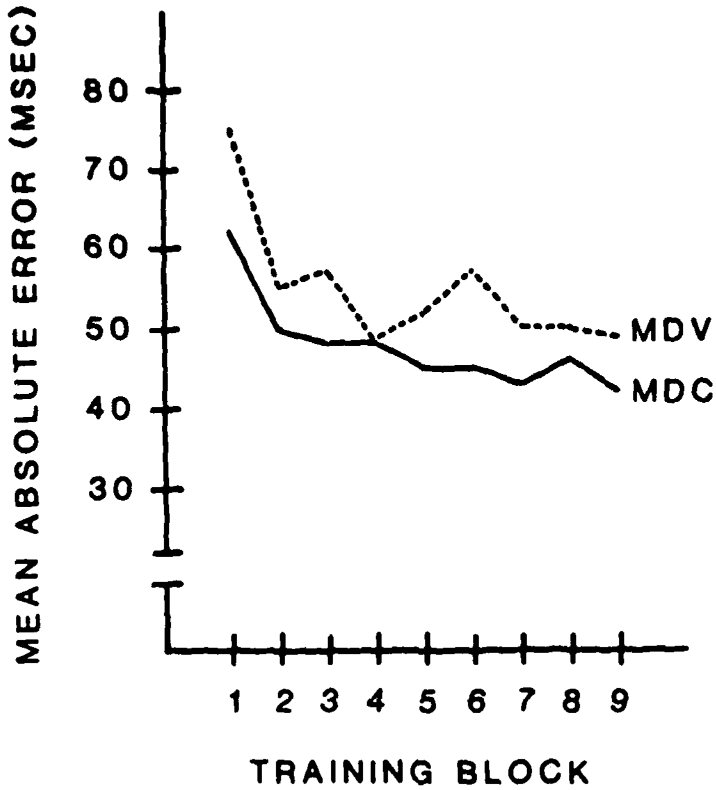

Figure 10.

Mean Absolute Error During the Training Phase for the Movement Distance x Blocks Interaction for Open Skills Subjects Receiving 45 Trials (9 Blocks)

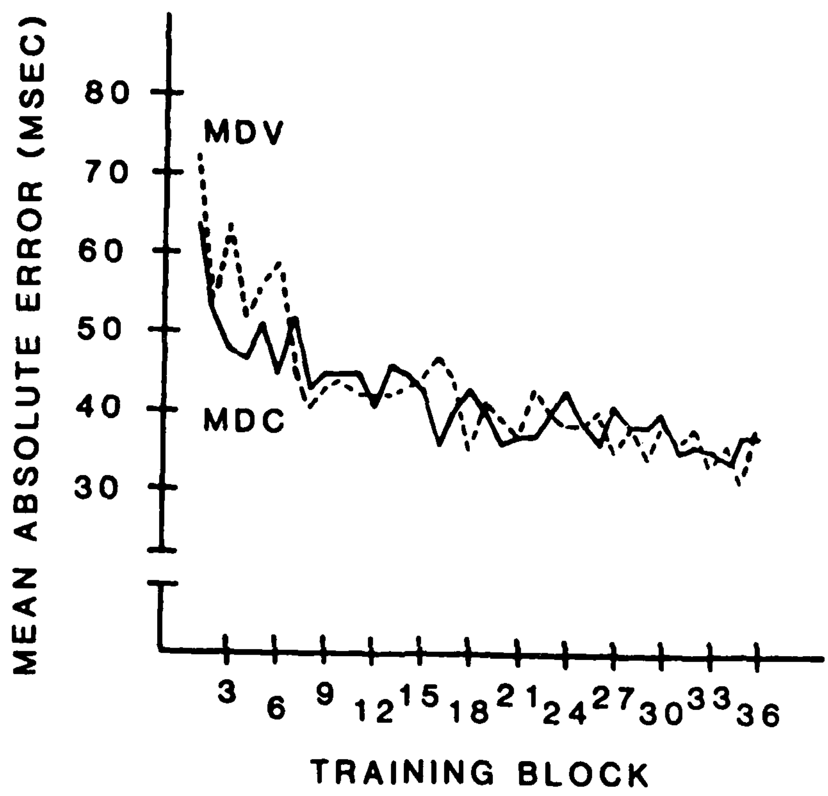

Figure 11.

Mean Absolute Error During the Training Phase for the Movement Distance x Blocks Interaction for Open Skill Subjects Receiving 180 Trials (36 Blocks) effects. Thus, it appeared that the absolute accuracy of a coincidence response involving a movement distance and stimulus velocity which had not previously been experienced was not influenced by either the amount or type of previous training experiences.

Constant error. For CE a significant interaction between training trials and stimulus velocity was obtained, $F(1,136) = 5.30$, $p < .05$. This interaction, presented in Figure 12, seemed to be caused primarily by differences in the CE performance of the groups receiving 45 training trials. Newman-Keuls procedures revealed that the CE of subjects receiving a constant stimulus velocity during 45 trials of training was significantly ($p < .05$) different from that of subjects who received varied stimulus velocities during their 45 training trials. The response bias of the former group was characterized by slightly early anticipations while that of the latter revealed an average tendency by subjects to strike the target after the illumination of the last lamp in the sequence. No difference was obtained between the CE of constant and varied stimulus velocity subjects receiving 180 training trials.

The only other significant effect for CE was a training trials x movement distance x blocks interaction, $F(3,408) = 3.61$, $p < .01$. The means and standard deviations for this interaction are presented in Table 2. While Newman-Keuls

Table 2

Means and Standard Deviations (in parentheses) for Constant Error During Transfer Blocks for the Training Trials x Movement Distance x Blocks Interaction (Open Skill Situation)

Training Movement Distance	Number of Training Trials	1	2	3	4
Constant	45	16(43)	-1(42)	2(41)	3(42)
	180	1(36)	11(37)	5(31)	-2(37)
Varied	45	0(50)	6(50)	2(36)	8(31)
	180	0(29)	-4(30)	-3(30)	-5(28)

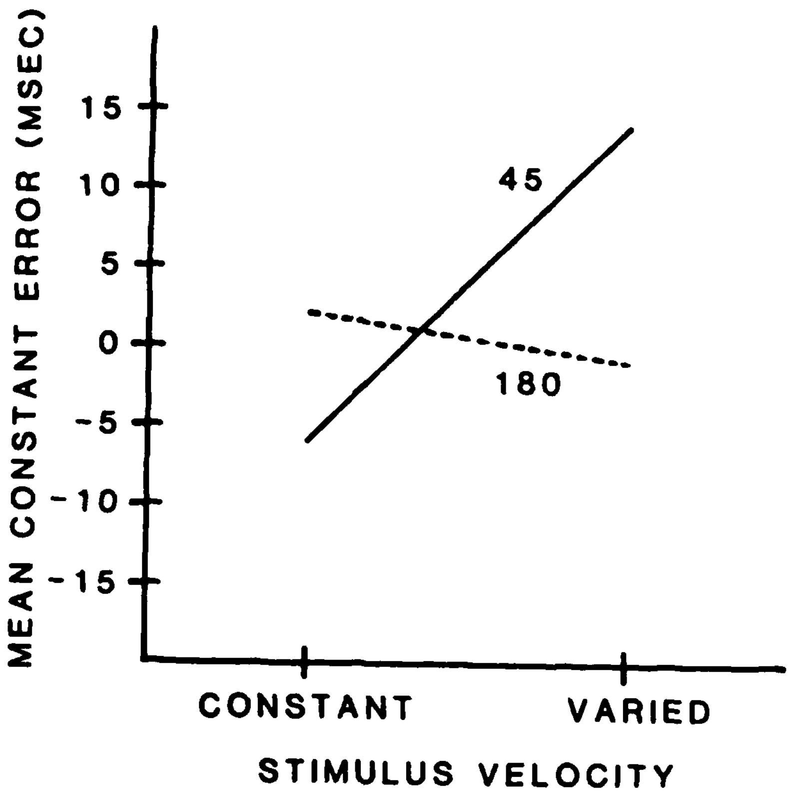

Figure 12.

Mean Constant Error During Open Skill Transfer for the Interaction Between Number of Training Trials and Stimulus Velocity Condition During Training analysis revealed no significant ($p < .05$) pairwise differences, it appeared that subjects who received a constant movement distance during 45 trials of training had more difficulty adjusting initially (i.e., on Block 1) to the transfer movement distance-stimulus velocity combination than did the other groups.

Variable error. There were three significant interactions, all involving the blocks factor, obtained for VE. These interactions, presented in Figures 13, 14, and 15 were training trials x blocks, $F(3,408) = 3.32$, $p < .05$, movement distance x blocks, $F(3,408) = 2.87$, $p < .05$, and stimulus velocity x blocks, $F(3,408) = 3.51$, $p < .05$, respectively. While no significant ($p < .05$) pairwise differences were obtained from the Newman-Keuls analysis for the training trials x blocks interaction (Figure 13), it appeared that the within-subject variability of coincidence responses for subjects receiving 180 training trials was slightly less on Blocks 2 and 3 of the transfer phase than that of subjects who received 45 training trials. With respect to the movement distance x blocks analysis, subjects receiving a constant movement distance during training significantly reduced their within-subject variability over blocks on the transfer task while subjects who received varied distances during training did not (Figure 14). Specifically, the VE of subjects in the fixed distance training condition, was significantly ($p < .05$) less on Blocks 3 and 4 than it was on Block 1. In a similar fashion, VE of subjects receiving a single stimulus velocity during training trials (Figure 15) was significantly ($p < .05$) reduced over transfer performance (i.e., VE on Block 1 was higher than that on Block 3) while that of subjects who trained with a variety of stimulus velocities was not.

Discussion

According to Schmidt's (1975) schema theory of discrete motor learning,

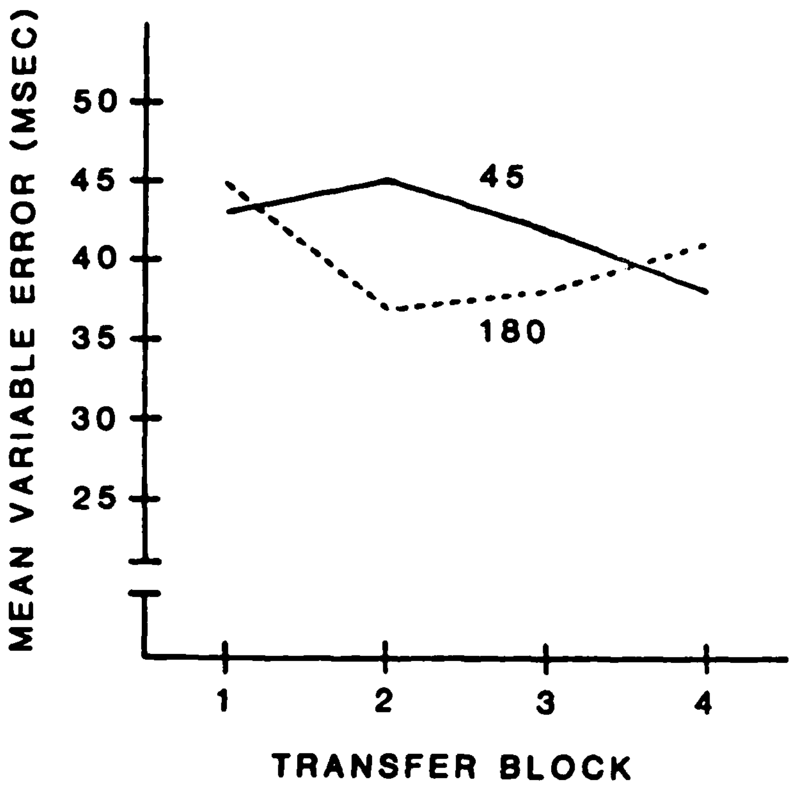

Figure 13.

Mean Variable Error on the Four Open Skill Transfer Blocks as a Function of Number of Trials Received During Training

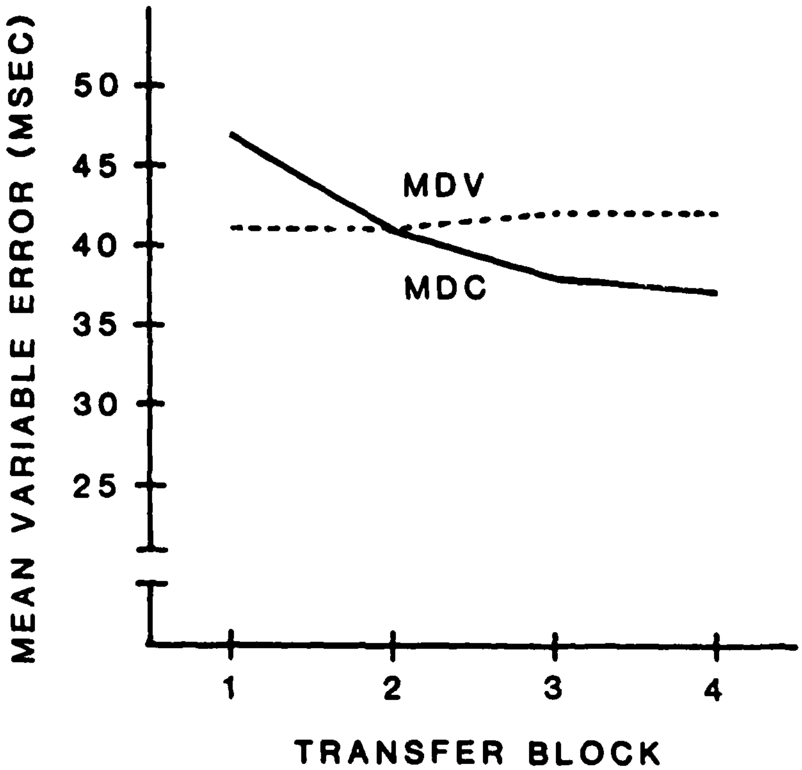

Figure 14.

Mean Variable Error on the Four Open Skill Transfer Blocks as a Function of Movement Distance Condition During Training

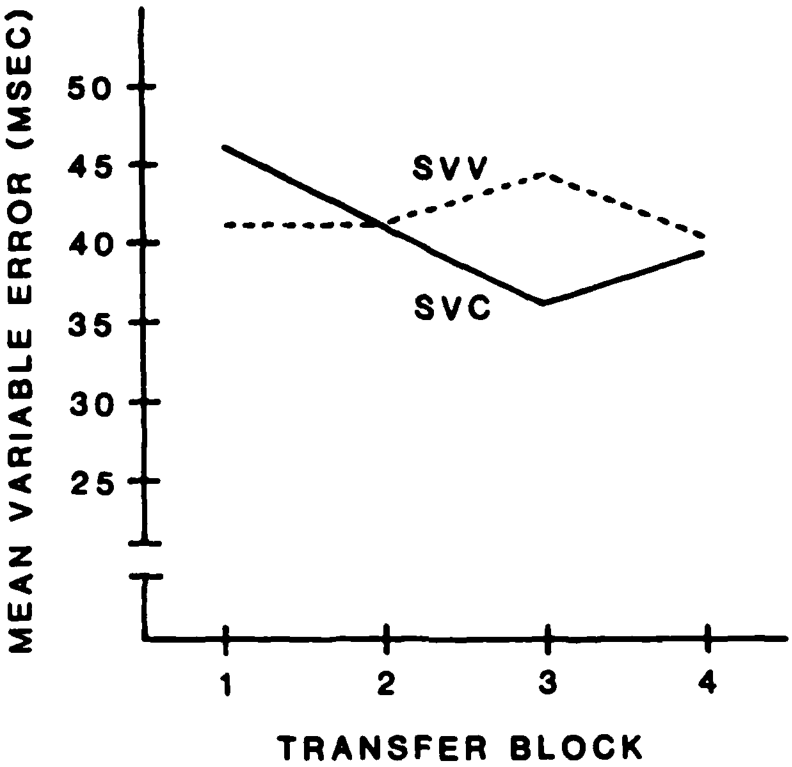

Figure 15.

Mean Variable Error on the Four Open Skill Transfer Blocks
as a Function of Stimulus Velocity Condition During Training

subjects over practice develop a generalized program for a particular class of responses (e.g., throwing). Schmidt specifically predicts that the strength of the program will be a function of the amount and variability of experiences the subject encounters during training. The present study attempted to test this prediction by manipulating the amount and variability of practice given on two different types of discrete timing tasks.

The first involved a closed skill (Poulton, 1957) in which subjects practiced making a ballistic arm movement from a start switch to a padded target. During training subjects received either 45 or 180 trials in which movement distance and/or movement time was fixed and/or varied from trial to trial. During this phase subjects were more accurate when movement time was held constant than when it was varied from trial to trial. Variations in movement distance had little influence on timing accuracy unless they were paired with variations in movement time. However, any error due to variations in movement distance disappeared after approximately 120 training trials. These results seem to coincide with the observation of Lordahl and Archer (1958) that variations in the temporal dimensions of a timing task cause greater disruptions in accuracy than do variations in spatial parameters. Moreover, the present finding of a transitory influence on performance due to variations in movement distance is consistent with the published results of Fleishman and Rich (1963) which demonstrated that spatial factors (e.g., movement distance) are more important primarily during the early phases of perceptual-motor performance.

In order to assess the strength of the generalized motor program developed during training subjects were transferred to a movement distance-movement time combination which they had not previously attempted. Schmidt's (1975) prediction of superior transfer performance by closed skill subjects who received a greater number of training trials was supported by the results of the ANOVAs performed on the AE and VE scores. Both the absolute accuracy and the within-subject consistency of subjects who received 180 training trials were superior to that of subjects who practiced for 45 trials. However, the prediction that the quality of transfer performance would be an increasing function of the variability of training experiences was not supported. In fact, where significant differences were obtained, the means were in the direction opposite to that predicted by the theory. Specifically, subjects who trained with a variety of movement times were less accurate (i.e., higher AE) and less consistent (i.e., higher VE) during transfer performance than their counterparts who trained with a constant movement time. In addition, subjects who performed with a variety of movement distances during training demonstrated higher within-subject variability during transfer performance than those who trained with a constant movement distance. Taken together the results of the transfer analysis for the closed skill situation suggest that variability in either the temporal or spatial dimensions of a discrete timing movement may not produce the most appropriate memorial representation for the production of a novel movement of the same general class.

That these results conflict with the findings of two earlier studies (McCracken & Stelmach, 1977; Newell & Shapiro, 1976) may be due to the fact that transfer in the present study was to a version of the task which required the production of <u>both</u> a new movement time and a new movement distance. In the earlier studies either movement time (McCracken & Stelmach, 1977) or movement distance (Newell & Shapiro, 1976) was the same for both the training and transfer phases of performance. Thus, it is possible that the transfer predictions of schema theory (Schmidt, 1975) may only apply in closed skill situations in which subjects are transferred to a version of the task which has at least one dimension in common with that experienced during training. Further investigation of this issue is obviously needed.

The second situation explored in the present study involved the acquisition and transfer of an open skill (Poulton, 1957). In this situation subjects performed a ballistic arm movement which they attempted to complete (i.e., by striking a hinged target) at the same moment that a visual light pattern was completing its sequence. During training subjects received either 45 or 180 trials in which movement distance and/or stimulus velocity was fixed and/or varied from trial to trial. The results from the training phase indicated that variations in movement distance resulted in lower absolute accuracy of anticipations. However, this influence which appeared to vanish early in training (i.e., after approximately 30 trials of practice), is consistent with the finding of Fleishman and Rich (1963) that spatial factors are primarily important during the initial stages of performance on an open timing task.

Following training all subjects received 20 transfer trials with a movement distance-stimulus velocity combination that they had not previously experienced. With respect to absolute accuracy (i.e., AE) of transfer performance it did not appear that differences in either the amount or variability of training experiences influenced the production of a novel coincidence anticipation response. Moreover, given sufficient practice (i.e., more than 50 trials) there was no evidence that response bias (i.e., CE) on the transfer task was influenced by variations in movement distance or stimulus velocity during training. With respect to within-subject variability during transfer performance subjects who trained under fixed movement distance or stimulus velocity conditions adjusted more rapidly (i.e., manifested significant decreases in within-subject variability over transfer blocks) to the novel movement distance-stimulus velocity combination than did subjects trained under varied conditions.

All in all the results from the open skill situation suggest that differences in the amount or variability of training experiences are of little importance to the performance of a novel movement distance-stimulus velocity combination. The lack of consistency of this result with that reported by Wrisberg and Ragsdale (1979) may be due to differences in the amount of training given in the two studies. It may be that a brief amount of varied practice on an open skill has a temporary benefit for immediate transfer to a new version of the task (Wrisberg & Ragsdale, 1979). However, extended practice (as in the present study) might be expected to produce similar levels of transfer to a novel version of the task regardless of the extent to which training is varied.

From a practical standpoint the results of the present study suggest that decisions regarding the quality and quantity of training experiences are more crucial for the learning of closed skills (e.g., throwing a hand grenade at a fixed target) than open skills (e.g., accurate estimation of the moment of initiation of an anti-tank response). Of particular importance is the implication that variations in the movement time, or to a lesser extent the movement distance of a closed timing movement during training may lead to greater errors in the production of a subsequent movement distance-movement time combination which has not been previously attempted. Thus, it might be concluded that transfer to a single novel version of a particular closed skill (e.g., repeatedly throwing a grenade at a new target) would benefit most from constant practice (i.e., fixed target, movement distance, and movement time) during initial training.

A potentially significant line of future inquiry would be to determine which type of practice, varied or constant, would promote transfer to a variety of novel versions of a closed task (e.g., throwing grenades at a number of previously unpracticed targets). In light of recent theorizing which addresses the potential of context effects on performance and learning (Jenkins, 1977; Tulving & Thompson, 1973) it might be argued that varied practice in the present study would have been more appropriate if closed skill transfer were to a context involving the production of a variety of novel movements. As it was, transfer performance occurred in a constant context (i.e., fixed movement distance and fixed movement time) while training performance ranged from completely constant (i.e., fixed movement distance-fixed movement time) to completely varied (i.e., varied movement distance-varied movement time). More research is obviously needed to sort out the role of context effects in the training and transfer of closed skills.

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